A Appendices

Appendix A

Observations for identifying Earth system variations and trends

Parameter	Implementation	Readiness	Operational Phase	Partnerships	Related In Situ
How are global precipitation, evaporation, and the cycling of water changing?					
Atmospheric Temperature	Passive sounding	Excellent	NPOESS	EUMETSAT coordination	Radiosondes (NOAA, WWW, NASA, NDSC)
	Active sounding (GPS)	Demonstration needed	NPOESS	EUMETSAT coordination	Global GPS network
Atmospheric Water Vapor	Passive sounding	Satisfactory	NPOESS	EUMETSAT coordination	Radiosondes, Ly- , μwave (NASA, NOAA, WWW)
Global Precipitation	Core radar satellite with 6–8 passive μwave satellite constellation	Demonstrated by TRMM and passive μwave imagers	Passive μwave	TRMM with Japan	Rain gauges, weather radar (NOAA, WWW)
Soil Moisture		Very large real or synthetic antenna to be demonstrated	Highly desired; subject to operational viability	Likely with European Space Agency	Neutron probes, lysimeters (USDA, USGS, FAO)
How is the global ocean circulation varying on interannual, decadal, and longer time scales?					
Ocean Surface Topography		Demonstrated. Development needed for denser coverage	Under study by NPOESS	Continuation of current partnerships likely	Tide gauges (Global Geodedic Network)
Ocean Surface Winds	Active/passive μwave	Demonstrated by NSCAT and Seawinds	NPOESS	Seawinds and follow-on with Japan	Ships, buoys (NOAA, WWW)
Sea Surface Temperature	IR and μwave	Excellent	NPOESS	EUMETSAT	Ships, buoys (NOAA, WWW)
Sea Ice Extent	μwave	Excellent	NPOESS	NASDA	Ships, airborne reconnaissance (Navy, USCG, NOAA)
How are global ecosystems changing?					
Terrestrial Primary Productivity	≤1 km resolution	Excellent MODIS	NPOESS	EUMETSAT	Inventory (USDA, FAO, NSF, GTOS)
Marine Primary Productivity		Demonstrated SeaWiFS, MODIS	NPOESS (Partial)	Japan and Europe (tentative)	SIMBIOS time series studies (NASA)
Classification,Functional Groups	Hyperspectral, Lidar	Demonstrated by EO-1 (Partial)	NPOESS (Partial) LDCM (Partial)	NOAA, USGS	Habitat structure, forest inventory, AUV, aircraft, moorings
How is atmospheric composition changing?					
Total Column Ozone		Excellent	NPOESS	EUMETSAT	Dobson, Brewer, FTIR, UV/VIS (NASA, NOAA)
Ozone Vertical Profile		Excellent	NPOESS	International coordination	Ozonesondes, Lidar, μwave , IR, (NASA, NOAA)

Appendix B

Observations for determining primary forcings on the Earth system

Parameter	Implementation	Readiness	Operational Phase	Partnerships	Related In Situ
What trends in atmospheric constituents and solar radiation are driving global climate?					
Total Solar Irradiance		Excellent	NPOESS		Global surface networks (BSRN, WRDC, SURFRAD)
Solar UV Irradiance		Excellent	NPOESS (planned)		USGCRP UV network, NDSC (multiagency)
Stratospheric Aerosol Distribution		Excellent	NPOESS (pending sufficient resolution)		Lidar, backscatter-sondes (NASA, NOAA, NSF)
Total Aerosol Amount		Excellent	NPOESS		AERONET, USDA network, NOAA/BSRN, DOE/ARM
Aerosol Properties		Further development needed		Important for ground-based measurements	AERONET, NOAA/CMDL, airborne aerosol spectrometers
Surface Trace Gas Concentration		Simpler instruments with higher temporal resolution needed	AGAGE	Support ground network	NASA AGAGE, NOAA flask network
Volcanic Gas & Ash Emissions		Further development to characterize troposphere constituents	Aviation requirements		Optical calibration
What changes are occurring in global land cover and land use, and what are their causes?					
Fire Occurrences	Global IR & visible or near IR; hyper-spectral for fuel load	Excellent MODIS,TRMM; EO-1 (Partial)	NPOESS, EDR application		Aeronet (NASA), burn scar inventory (USFS), optical calibration
Trace Gas Sources	CO_2 column mapping is greatest priority	OCO in definition phase	Not currently an operational requirement		Flask network (NOAA), Ameriflux (DOE, USDA, NASA), FluxNet
Land Cover & Land Use	High spatial resolution visible	Excellent Landsat; EO-1	LDCM	Commercial data purchase	Land Cover Maps (USGS), Vegetation Inventories (DOI, USDA)
What are the motions of the Earth's interior, and how do they directly impact our environment?					
Interior Motions of the Earth		Excellent	Multi-agency infrastructure	Exploratory missions	SLR, GPS, VLBI networks, magnetometer observations
What changes are occurring in the mass of the Earth's ice cover?					
Ice Surface Topography		ICEsat lidar altimetry demonstration		Coordination with European radar altimetry satellite	GPS (NASA, NSF)

Parameter	Implementation	Readiness	Operational Phase	Partnerships	Related In Situ
How is the Earth's surface being transformed by naturally occurring tectonic and climatic processes?					
Gravity Field		GRACE	DOD interests		Geodetic networks
How is the Earth's surface being transformed by naturally occurring tectonic and climatic processes?					
Terrestrial Reference Frame	Ground observation & precision satellite tracking	Excellent	Multi-agency infrastructure	Multi-national ground network	SLR and GPS networks
Surface Stress, Deformation	Focus on active earthquake & volcanic regions	Excellent	Local agency support of ground arrays	Multi-national ground arrays	Regional GPS networks, geological obsservations

Appendix C

Observations to characterize Earth system responses and feedbacks

Parameter	Implementation	Readiness	Operational Phase	Partnerships	Related In Situ
What are the effects of clouds and surface hydrologic processes on Earth's climate?					
Cloud System Structure	Multi-spectral visible & IR radiometry	Excellent	NOAA & NPOESS	EUMETSAT & Japanese ADEOS/GLI	Radiosondes, lidar (NASA, NOAA, FAA)
Cloud Particle Properties & Distribution	Active sensor to resolve 3-D structure	Demonstration of cloud radar and lidar pending			Altitude-resolved cloud particle data
Radiation Budget	Broadband radiometry	Excellent	NPOESS		Cloud and aerosol properties
Soil Moisture					neutron probes, lysimeters (USDA, USGS, FAO)
Snow Cover & Accumulation		Awaiting demonstration	NPOESS		Snow transects (NOAA/NWS)
Freeze-Thaw Transition		Awaiting demonstration			
How do ecosystems, land cover and biogeochemical cycles respond to and affect global environmental change?					
Terrestrial Biomass	Active sensor to resolve canopy structure	Awaiting demonstration			Crop-timber yields (USDA, DOI), carbon database (DOE)
Marine Biomass & Productivity		Excellent SeaWiFS, MODIS (Partial)	NPOESS (Partial)		Gliders, AUV's, moorings, floats (NASA, NOAA)
Carbon Sources and Sinks		OCO in definition phase			Flask network (NOAA), AmeriFlux/FluxNet (DOE, USDA, NASA)
How can climate variations induce changes in the global ocean circulation?					
Sea Surface Salinity	Very high radiometric precision passive μwave	Awaiting demonstration	NPOESS	European Space Agency	Ships and moored/drifting buoys (NOAA, NSF)
Sea Ice Thickness					Moored buoys (ONR)
How do atmospheric trace constituents respond to and affect global environmental change?					
Atmospheric Properties in Tropopause Region		Limb viewing sensors not yet demonstrated			Sondes (WWW, NOAA)
How is global sea level affected by natural variability and human-induced change in the Earth system?					
Polar ice sheet velocity	Synthetic aperture radar interferometry and image feature tracking	Demonstrated			GPS (NASA, NSF)

Appendix D

Observations for studying the consequences of Earth system change

Parameter	Implementation	Readiness	Operational Phase	Partnerships	Related In Situ
How are variations in local weather, precipitation and water resources related to global climate variation?					
Global Precipitation	Core radar satellite with 6–8 passive mwave satellite constellation	Demonstrated by TRMM and passive μwave imagers	Passive mwave	TRMM with Japan	Rain gauges, weather radar (NOAA, WWW)
Ocean Surface Winds	Active μwave	Demonstrated by NSCAT and SeaWinds		Seawinds cooperation with Japan; EUMETSAT	Ships, buoys (NOAA, WWW)
	Passive μwave radiometry/polarimetry	Windsat/Coriolis demonstration	NPOESS		N/A
Meteorological Properties Around Storms	Vertical profiling from a geostationary platform	Demonstration by GIFTS			Radiosondes (NOAA, WWW)
Lightning Rate	Geostationary	Demonstrated by OTD and LIS			Sferics (NOAA)
River Stage Height/ Discharge Rate		Capability demonstrated by Topex/Poseidon			River gauges (USGS)
What are the consequences of land cover and land use change for human societies and the sustainability of ecosystems?					
Primary Productivity	Global 1 km or better resolution needed	Excellent MODIS, Landsat	NPOESS LDCM	EUMETSAT	NASA-SIMBIOS, GOOS, GTOS, crop, forest inventories (USDA, FAO), LTER (NSF)
Land Cover/Land Use Change	High spatial resolution required	Excellent MODIS, (250m), Landsat, EO-1	LDCM NPOESS (Partial)	Commercial data sets	Land cover maps (USGS), vegetation inventories (DOI, USDA)
Functional Groups and Classification	Hyperspectral, Lidar	Moderate Demonstrated by EO-1 (Partial)	Partial by LDCM NPOESS	NOAA, USGS	Habitat structure, forest inventory, AUV, aircraft, moorings
What are the consequences of climate change and increased human activities for coastal regions?					
Coastal Region Properties and Productivity	Multispectral radiometry at high spatial and temporal resolution from GEO	Excellent			Coastal observations (NOAA, EPA)

Appendix E

Observations for predicting Earth system change

Parameter	Implementation	Readiness	Operational Phase	Partnerships	Related In Situ
How can weather forecast duration and reliability be improved?					
Tropospheric Winds	Active doppler lidar	Technical developments, demonstration needed		Commercial data purchase possible	Rawinsondes (NOAA, WWW)
Ocean Surface Winds	Active μwave	Demonstrated by NSCAT & SeaWinds		Seawinds cooperation with Japan; EUMETSAT	Ships, buoys (NOAA. WWW)
	Passive μwave radiometry/ polarimetry	Windsat/Coriolis demonstration	NPOESS		
Ocean Surface Salinity	Passive μwave radiometry	Aquarius in definition phase		Joint with Argentina	CTD, ARGO, XCTD
Cloud Microphysics	Polarimetric data	Demonstrated		NOAA, DOD	Aircraft sampling in field campaigns
Global Precipitation	6-8 satellite constellation	Demonstrated by TRMM & passive mwave imagers			Rain gauges, weather radar (NOAA, WWW)
Freeze-Thaw Transition		Awaiting demonstration			
Lightning Rate	Geostationary	Demonstrated by OTD and LIS			Sferics
Soil Moisture		Approaching readiness			Neutron probes, lysimeters (USDA, USGS, FAO)
Sea Surface Temperature	IR & μwave	Excellent	NPOESS	EUMETSAT coordination	Ships, buoys (NOAA, WWW)
How can predictions of climate variability and change be improved?					
Ocean Surface Topography	Non-polar orbit to avoid tidal aliasing	Demonstrated ; development needed for denser coverage	NPOESS (polar orbit is problematic)		Tide gauges; Global Geodetic Network for reference frame
Ocean Bottom Pressure & Topography	Enhanced satellite altimetry through better Topex tracks.	WOCE, GODAE research projects provide initial data base	Operational Global Ocean Observing System	Multi-agency, international cooperation is anticipated	Ships and ARGO floats (NOAA, NSF)
Ice Sheets	Lidar	Demonstrated			Mass balance
Sea-Ice Cover, Extent, Concentration and Thickness	Passive μwave, SAR scat, VIS/IR, altimetry	Very good in μwave and SAR, thickness requires demonstration		NOAA, DOD	Buoys, ice breakers, submarines
Ocean Heat		Demonstrated		NOAA	Deep sounding buoys

Parameter	Implementation	Readiness	Operational Phase	Partnerships	Related In Situ
How will future changes in atmospheric composition affect ozone, climate, and global air quality?					
Total Column Ozone		Excellent	NPOESS	EUMETSAT coordination	Dobson, Brewer, FTIR, UV/VIS (NASA, NOAA)
Aerosol		Good		EPA	Aeronet, sunphotometers, micro pulser lidar network
How will carbon cycle dynamics and terrestrial and marine ecosystems change in the future?					
Trends in carbon sources and sinks	CO_2 and CH_4 column mapping	OCO for CO_2 in definition phase: CH_4 needs further development	Not currently and operational requirement		Flask network (NOAA), Ameriflux/FluxNet (DOE, USDA, NASA)
Surface Properties & Primary Productivity	High spatial resolution	Excellent, Lidar, InSAR, and optical need development and need to reduce cost. MODIS, Landsat	Partially by NPOESS	Commercial data purchase possible; ESA, JAXA, CSA; EUMETSAT coordination	Land cover maps (USGS), Vegetation inventories (DOI, USDA)
Trends in biomass	Lidar, radar	Awaiting demonstration			Crop, forest inventory (USDA, FAO, NSF, GTOS); Ameriflux/Flux Net (DOE, USDA, NASA); SIMBIOS
Functional Groups and Classification	Hyper-spectral, Lidar	Demonstrated by EO-1	Partially provided by NPOESS, LDCM	NOAA, USGS	Habitat structure, forest inventory, AUV, aircraft, moorings
How can our knowledge of earth surface change be used to predict and mitigate natural hazards?					
Surface Deformation	InSAR with 1 mm/yr surface displacement	Good/awaiting demonstration		NSF	GPS, seismology, borehole strain (NASA/NSF/USGS)
High-Resolution Topography	SRTM data, imaging lidar; data sets, German X-SAR and optical data e.g., ASTER, and ERS-1/2 tandem mission	Technology development for space-based lidar, formation flying InSAR at L Band		USGS, NIMA	
Earth's Magnetic Field		Good		Excellent-NIMA, Europeans ESA, DLR, DSRI, CONAE, ASI, ISA	Intermagnet ground network
Earth's Gravity Field	GRACE and CHAMP analysis	Good	ESA GOCE	ESA, DLR, NIMA	Ocean bottom and atmospheric pressure essential